Water quality status of a USDA water quality demonstration project in the Eastern Coastal Plain

K.C. Stone, P.G. Hunt, S.W. Coffey, and T.A. Matheny

ABSTRACT: A 5-year research study was initiated in 1990 at the USDA Water Quality Demonstration Project in the Herrings Marsh Run (HMR) watershed in Duplin County, North Carolina. The HMR watershed is representative of an eastern Coastal Plain watershed with intensive agricultural practices (e.g., crop, swine, poultry, and cattle production). Stream water sampling stations were established at four locations in the watershed to evaluate the influences of the agricultural practices on stream water quality. Stream water at the HMR Tributary (Station 2) was consistently lower in quality than water from the HMR Main channel (Station 3). Nitrate-N levels normally exceeded 5 mg/L in stream water at the HMR Tributary. These data indicate that current and past agricultural management practices have degraded stream water quality at specific locations. Implementation of improved management practices has the potential to produce measurable improvements in the quality of water in the demonstration watershed.

Even though significant progress has been made in developing and implementing agricultural best management practices, nonpoint pollution of surface water and groundwater by agriculture is a major water quality concern (Bjerke 1989; Bouwer 1987; Hurlburt 1988; Hubbard et al. 1986; Hubbard and Sheridan 1989). A 5-year water quality demonstration project involving federal, state, and local agencies; private industry; and local land owners was initiated in 1990 on a watershed located on the Cape Fear River Basin in Duplin County, North Carolina. The 2044-ha (5050-ac) demonstration watershed, Herrings Marsh Run (HMR), is one of the eight original demonstration projects funded as part of the USDA's Presidential Water Quality Initiative, and it is located within the Goshen Swamp Watershed, one of the 37 original Hydrologic Unit Area Projects (United States Department of Agriculture and Cooperating State Agencies 1989). Duplin County has many characteristics of an intensive agricultural county in the eastern Coastal Plain of the United States. Duplin County has the highest agricultural revenue of any county in North Carolina. In 1990, it had the highest population of turkeys and the fourth highest population of swine of any county in the United States (North Carolina Dept. of Agriculture 1990).

Agricultural management practices on the watershed are typical for the southeastern Coastal Plain and include 1,093 ha (2,700 ac) of cropland; 708 ha (1,750 ac) of woodlands; and 212 ha (525 ac) of farmsteads, poultry facilities, and swine facilities. The major agricultural crops on the watershed include corn 415 ha (1,025 ac), soybeans 273 ha (675 ac), vegetables 153 ha (378 ac), tobacco 131 ha (325 ac), and wheat 121 ha (300 ac). The predominant soil series in the watershed is Autryville (loamy, siliceous, thermic Arenic Paleudults); secondary soil series are Norfolk (fine-loamy, siliceous, thermic Typic Kandiudults), Marvyn-Gritney (clay, mixed, thermic Typic Hapludults), and Blanton (loamy siliceous, thermic Grossarenic Paleudults).

Current annual nutrient usage for crop production on the watershed is estimated at 145 metric tons of nitrogen, 64 metric tons of phosphorus, and 243 metric tons of potassium. Although swine and poultry operations produce sufficient quantities of waste to supply more than half of the needed nutrients, 90% of the nutrients applied to cropland are supplied by commercial fertilizers. The application of large quantities of commercial fertilizers coupled with the production of large quantities of animal waste provides a potential for nitrogen and phosphorus contamination of surface water and ground-

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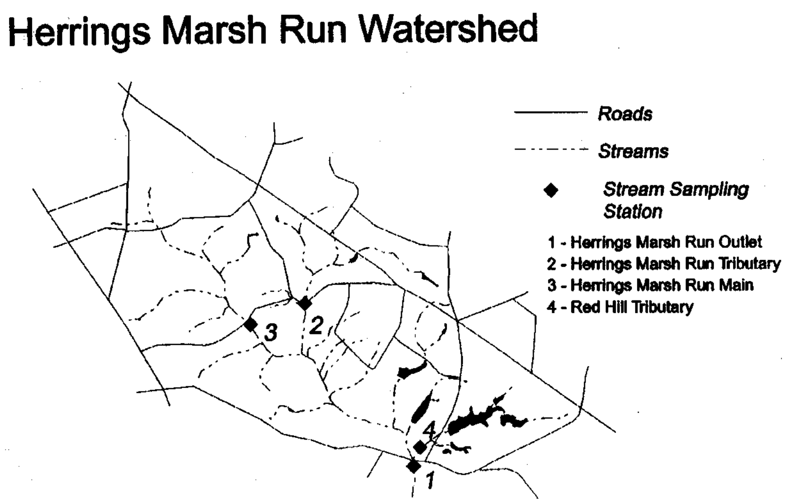

Figure 1. Location of stream gaging stations on Herring Marsh Run watershed

water. The objective of the initial phase of this project has been to evaluate the effect of current agricultural management practices on stream water and groundwater quality within the watershed.

Methods

Surface water sampling stations were established in August 1990 at three locations within the watershed (Figure 1). Station 1, Red Hill, was located at the stream outlet from the watershed. Station 2, HMR Tributary, was located along a tributary downstream from intensive swine and poultry operations. Station 3, HMR Main, was located along the upper portion of the main stream that flowed through woodlands. The woodlands located above Station 3 had a substantial riparian buffer compared with Station 2. Station 3 was chosen to represent background conditions because of its large riparian buffers and the absence of animal production facilities in the subwatershed. Station 4, Red Hill Tributary, was installed in August 1991 to provide additional information about the eastern portion of the watershed. ISCO 2700 automated water samplers were installed at each station. Sample collection was continual from October 1990 to the present time. The water samplers combined hourly samples into a daily composite. The samples were collected weekly and transported to the laboratory for analyses. The U.S. Geological Survey in Raleigh, North Carolina, installed and maintained gaging stations at the initial three stations in April 1991. A gaging station was installed at Station 4 in August 1991. The gaging stations measured flow at 15-min intervals using automated water level recorders.

All water samples were transported to the USDA-Agricultural Research Service (ARS), Soil, Water, and Plant Research Center in Florence, South Carolina, for analyses. Water samples were analyzed using a TRAACS 800 Auto-Analyzer for nitrate-N, ammonium-N, total Kjeldahl nitrogen, ortho-phosphate, and total phosphorus using EPA Methods 353.2, 350.1, 351.2, 365.1, and 365.4, respectively (U.S. EPA 1983). EPA-certified quality control samples were routinely analyzed to verify results.

All statistical analysis of the data was accomplished using SAS version 6.07 (SAS 1990). Hydrograph separation was performed on the streamflow data. This provided a method to divide the streamflows into storm and base flow conditions. A graphical method described by Viessman et al. (1977) was used to separate the storm and base flows. The storm and base flows were then integrated with the concentration data to provide an estimate of the solute fluxes. The technique used to estimate the solute fluxes is described by Lesack (1993). The method calculates the solute flux at discrete time intervals as the product of the concentration and flow. Solute fluxes that contribute to the base and storm flows are calculated by using a mass balance equation:

$$CQ = C_B Q_B + C_S Q_S$$

where C_B and Q_B are the concentration and discharge at base flow, C_S and Q_S are the concentration and discharge at storm flow; C and Q are the measured concentration and flow, respectively. Calculation of the component concentrations is then performed.

A simple nitrogen and phosphorus mass balance was calculated using results of farm surveys (Coffey 1994; NCSU 1991). Nitrogen inputs (fertilizer N, livestock waste N, and legume residual N) and outputs (crop N and residue N) were recorded in the farm surveys. A similar analysis was done for phosphorus. The differences between the inputs and outputs were calculated and values of excess N and P were obtained. The excess N and P from the surveys were then compared with the observed stream loading rates of N (NO_3+NH_4) and P (PO_4) at each sampling station.

Results and discussion

Mean nitrate-N concentrations of water leaving the watershed outlet, Red Hill (Station 1), and at the HMR Tributary (Station 2) were two- and four-times higher, respectively, than background concentrations as represented by HMR Main (Station 3) (Table 1). Daily mean nitrate-N concentrations (Figure 2) at the HMR Tributary sometimes exceeded 10 mg/L and frequently exceeded 6 mg/L. Overapplied swine lagoon effluent and undersized, overloaded lagoons were likely con-

Table 1. Means and standard deviations (in parentheses) for nitrate-N, ortho-phosphate, and ammonium-N concentrations (mg/L) and in storm and base flow for the Herring Marsh Run (HMR) watershed

	Station							
	1		2		3		4	
Flow	Red Hill		HMR Tributary		HMR Main		Red Hill Tributary	
			NO_3-N (mg/L)					
Storm	2.5	(2.6)	5.4	(4.8)	1.4	(1.7)	1.1	(1.1)
Base	2.1	(0.6)	5.6	(1.9)	1.1	(0.4)	1.5	(0.6)
			NH_4-N (mg/L)					
Storm	.59	(1.20)	2.28	(3.88)	.32	(0.65)	.68	(1.09)
Base	.28	(0.28)	.74	(0.90)	.19	(0.25)	.43	(0.53)
			PO_4* (mg/L)					
Storm	.81	(2.24)	1.3	(1.22)	.20	(0.38)	.85	(1.65)
Base	.78	(1.46)	.68	(0.41)	.12	(0.14)	.29	(0.30)

* These are intermediate values between the truly soluble and the total phosphorus values because the acidification process used for preservation in the autosampler bottles solubilized some of the phosphorus in the solid phase of the samples.

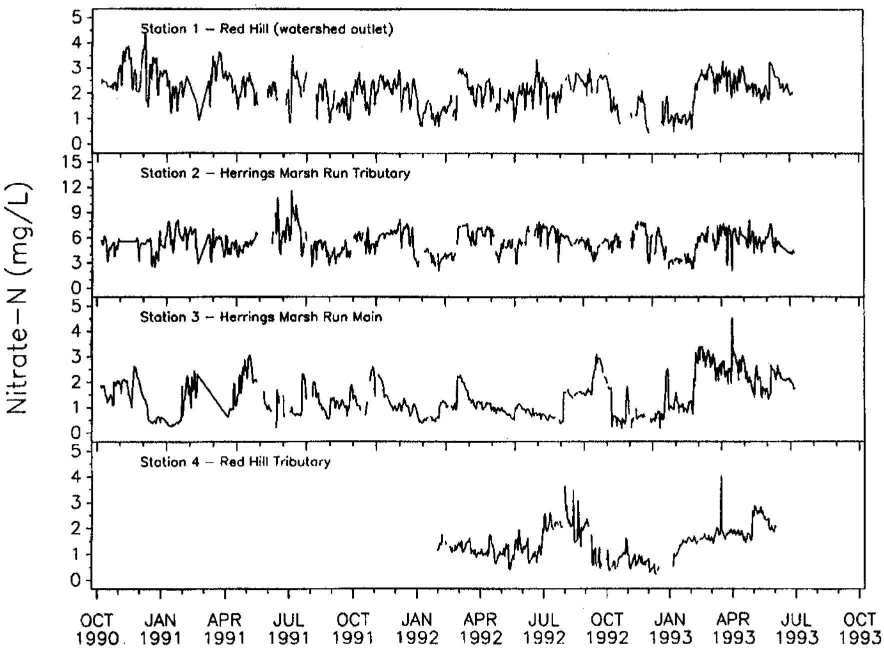

Figure 2. Nitrate-N concentrations in stream water for Herrings Marsh Run watershed

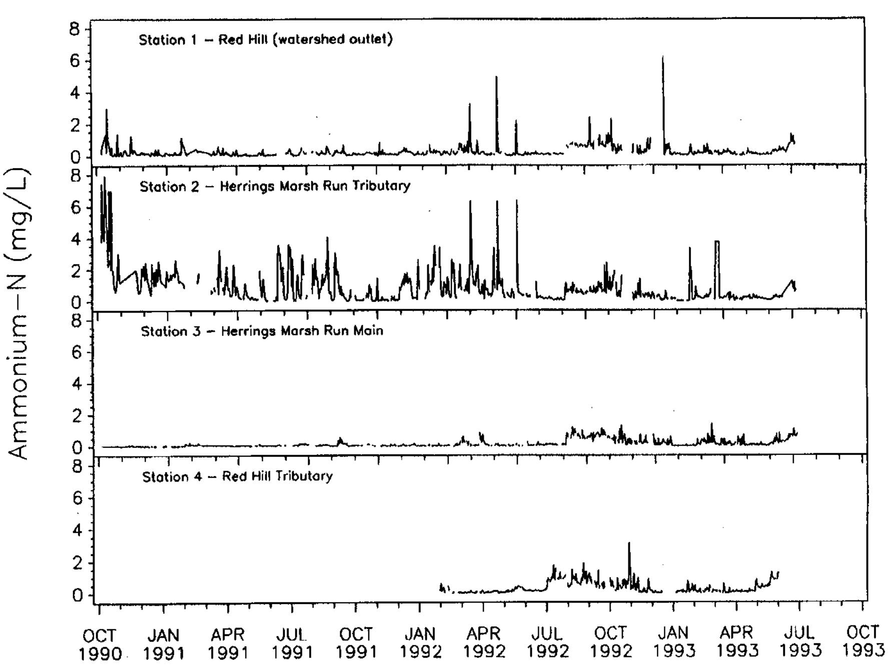

Figure 3. Ammonium-N concentrations in stream water for Herrings Marsh Run watershed

tributors to the elevated nitrate-N concentrations in the HMR Tributary.

Mean ammonium-N concentrations of water at the watershed outlet and at the HMR Tributary (Station 2) were approximately two- and four-times higher, respectively, than background concentrations (Table 1). Ammonium-N concentrations at the watershed outlet and at HMR Tributary exceeded limits considered harmful to humans (0.5 mg/L) and fish (2.5 mg/L) (U.S. EPA 1973). During the first month of the sampling period, daily ammonium-N concentrations at the HMR Tributary ranged from 6 to 12 mg/L (Figure 3). These high concentrations of ammonium-N indicated that a significant discharge of animal waste products into the waterway had occurred. After the first month, daily mean ammonium-N concentrations did not exceed 4 mg/L. High ammonium-N concentrations were thought to be caused by an undersized swine lagoon occasionally overflowing upstream from Station 2. The undersized lagoon was expanded April 1992. After the lagoon was expanded, ammonium-N spikes were infrequent at Station 2.

Mean ortho-phosphate concentrations of water at the watershed outlet (Red Hill, Station 1) and at HMR Tributary (Station 2) were approximately five times higher than background concentrations at HMR Main (Station 3). This was likely a result of suspended solids in the samples and the associated solubilization of phosphorus in the acidified samples. Grab samples (filtered to 0.45 µm prior to acidification to remove suspended solids) showed low levels (<0.20 mg/L) of soluble phosphorus throughout the watershed.

Streamflow data from the USGS gaging stations (USGS 1992) are shown in Figure 4. The flow data began in April 1991 for three stations (Red Hill, HMR Tributary, and HMR Main) and August 1991 for the Station 4 (Red Hill Tributary). The streamflow data were integrated with the stream monitoring data to calculate the mass loading of nitrate-N and ammonium-N. Mass nitrate-N leaving the watershed (Red Hill) averaged about 15 kg/day (33 lb/day). The HMR Tributary monitoring station had approximately 10.5 kg/day (23 lb/day) leaving that subwatershed. The mass ammonium-N at Red Hill and HMR Tributary frequently exceeded 3 and 2.5 kg/day (6.6 and 5.5 lb/day), respectively.

Results of the separation of the streamflow into base and storm flow components are shown in Tables 1 and 2. The concentrations show that the base flow concentrations are typically lower than the storm flow concentrations. The fluxes of nutrients from the sampling stations are shown in Table 2. At Stations 1, 3, and 4 the nutrient fluxes at base flows are lower than the storm flow fluxes. This suggests that at these stations, much of the export of nutrients is during storm flows. At Station 2, the storm flow fluxes of ortho-phosphate and ammonium-N follow the same pattern as the other stations with the storm flow fluxes being greater than the base flow fluxes. However, at Station 2, the nitrate-N flux at base flow is greater than the storm flow flux. This suggests that while the storm flows are contributing to the total flux of nitrate-N, the majority of the nitrate-N flux is coming directly from the base flow.

Excess applied N and P in the watershed and losses in stream water are shown in Table 3. The subwatershed above Station 2

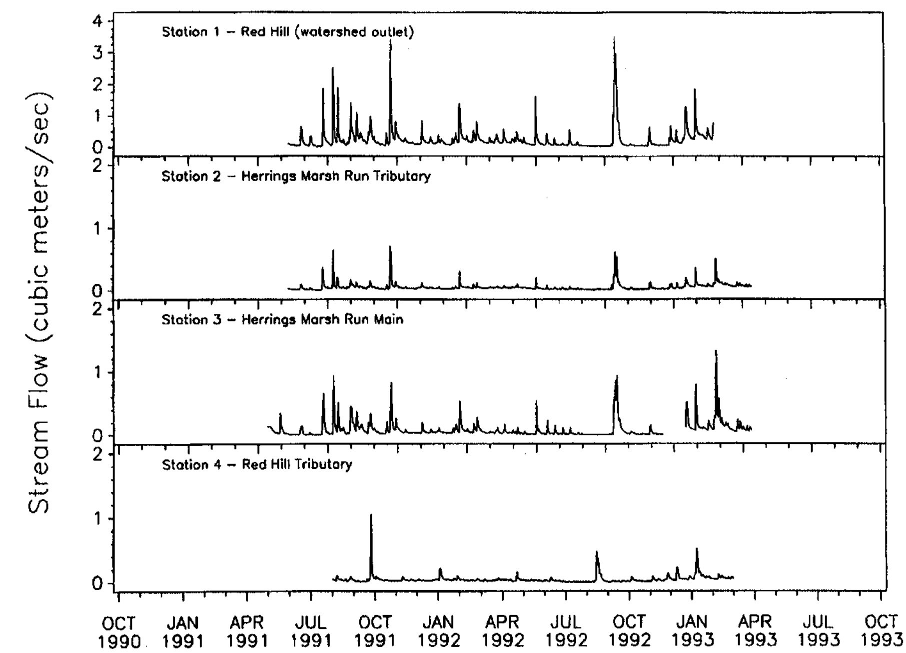

Figure 4. Provisional U.S.G.S. stream flow data for Herrings Marsh Run watershed

(Subwatershed 2) had the highest amount of excess applied N [85 kg/ha (75 lb/ac)] and the largest observed N in the stream water [22 kg/ha (20 lb/ac)]. Excess N applications in Subwatershed 2 are related to the number of acres that received applied animal waste. For the entire watershed, excess applied N was calculated at 38 kg/ha (34 lb/ac), and the observed N in stream water was 2.9 kg/ha (2.6 lb/ac). Excess applied P for the entire watershed was approximately 20 kg/ha (18 lb/ac) with 2.5% loss in stream water as ortho-phosphate. Subwatershed 2 also had the highest excess P application and highest ortho-phosphate loss (per hectare) to stream water. Ortho-phosphate loss to stream water in Subwatershed 2 was 6 times greater than the losses at the watershed outlet (Station 1).

Summary

Results from the initial phase of the 5-year project indicate that most of the streams in the watershed have acceptable water quality. The stream water at the watershed outlet (Station 1) and Station 2 had elevated nitrate-N and ammonium-N concentrations. The elevated nitrogen concentrations from Subwatershed 2 are thought to be directly related to the high density of swine production facilities and the reduced riparian buffers. Mass flux from Subwatershed 2 accounts for over two-thirds of the nitrate-N leaving the watershed at the watershed outlet. Separation of the nutrient fluxes into storm and base flow components indicated that storm flow nutrient fluxes were greater than the base flow nutrient fluxes for most sampling stations. However, the nitrate-N flux during base flow was greater than the storm flow flux at Station 2. This also suggests that Subwatershed 2 has an excess of nitrate-N probably from the high concentration of swine and excess application of nutrients. The N mass balance calculations and comparison with the stream N loadings show that 26% of the excess N applied is being lost to stream water in Subwatershed 2.

It appears that traditional agricultural management practices on the watershed have had a significant adverse impact on the quality of stream water at specific locations. Further, these data indicate that improvements in specific agricultural management practices on the watershed could produce measurable improvements in water quality on farms that have elevated nutrient concentrations.

Table 2. Means and standard deviations (in parentheses) for nitrate-N, ortho-phosphate, and ammonium-N flux (kg/day) from the watershed and subwatersheds in storm and base flows for the Herring Marsh Run (HMR) watershed

	Station							
	1		2		3		4	
Flow	Red Hill		HMR Tributary		HMR Main		Red Hill Tributary	
				NO_3-N (kg/day)				
Storm	9.2	(14.5)	4.9	(10.6)	3.8	(9.2)	0.9	(2.8)
Base	6.1	(3.1)	5.8	(2.7)	1.1	(1.1)	0.5	(0.2)
Total†	15.4	(14.3)	10.5	(10.7)	4.9	(9.3)	1.5	(2.8)
				NH_4-N (kg/day)				
Storm	2.51	(5.91)	1.92	(4.26)	0.91	(3.11)	0.46	(1.35)
Base	0.73	(0.61)	0.72	(1.04)	0.13	(0.20)	0.11	(0.12)
Total†	3.12	(5.98)	2.53	(4.51)	1.00	(3.13)	0.53	(1.36)
				PO_4* (kg/day)				
Storm	2.35	(6.28)	1.71	(4.29)	0.47	(1.49)	0.52	(2.69)
Base	2.35	(4.57)	0.75	(0.56)	0.07	(0.08)	0.08	(0.08)
Total†	3.08	(7.04)	2.40	(4.40)	0.54	(1.51)	0.59	(2.70)
				Flow (cubic meters/s)				
Storm	0.19	(0.39)	0.034	(0.077)	0.068	(0.144)	0.026	(0.069)
Base	0.09	(0.054)	0.034	(0.016)	0.003	(0.025)	0.018	(0.011)
Total†	0.25	(0.36)	0.056	(0.066)	0.080	(0.135)	0.040	(0.066)

* These are intermediate values between the truly soluble and the total phosphorus values because the acidification process used for preservation in the autosampler bottles solubilized some of the phosphorus in the solid phase of the samples.

† Total means are derived independently from the entire data set.

Table 3. Excess applied nitrogen and phosphorus and stream loadings for the Herrings Marsh Run (HMR) watershed

	Station			
	1	2	3	4
	kg/ha			
Excess N applied	38	85	55	26
Stream N* loading	2.9	22	6.3	3.7
Excess N % loss in stream	8%	26%	12%	14%
Excess P applied	20	57	15	4.5
Stream P* loading†	0.5	3.2	0.4	0.3
Excess P % loss in stream	2.5%	5.6%	2.7%	6.7%

* Stream N loading consisted of NO_3+NH_4 and Stream P consisted of PO_4.

† These are intermediate values between the truly soluble and the total phosphorus values because the acidification process used for preservation in the autosampler bottles solubilized some of the phosphorus in the solid phase of the samples.

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